NEWSLETTER

VOLUME 15 NUMBER 2 SUMMER 1977

AUSTRALIAN SOCIETY FOR LIMNOLOGY
NEWSLETTER

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THE AUSTRALIAN SOCIETY FOR LIMNOLOGY

The Australian Society for Limnology is an association of over 300 people with professional or amateur interests relating to Australian inland waters. Since its inception in 1961, the Society has played an important role in fostering limnological work in this country. The ASL also promotes liaison between limnologists in academic, private, and governmental institutions, and has a vested interest in the conservation of aquatic and related resources. Annual congresses are held near centres of limnological interest, and the program includes scientific sessions, field excursions, and social activities.

The ASL produces a Newsletter, with notes on activities, articles of general and scientific interest, book reviews, and congress announcements, and an occasional Special Publication. A further periodical publication is the Directory of Australian Limnologists.

Membership applications are welcomed; four classes of subscribing membership are catered for:

- Ordinary members ($8 p.a.)
- Student members ($4 p.a.)
- Sustaining members ($50 p.a. or more)
- Affiliated Bodies (subs. on application)

NOTE: Members are entitled to receive the *Aust. J. Mar. Freshwat. Res.* at a reduced rate ($4).

Subscriptions cover the period 1 July-30 June.

Details are available from:

Dr. B.T. Hart,
Hon. Sec./Treasurer, ASL.,
Department of Chemistry,
Caulfield Institute of Technology,
P.O. Box 197,
CAULFIELD EAST. 3145.
VICTORIA.

* * * * *

Newsletter contributions are always welcome, and correspondence should be addressed to the Newsletter Editor.

ASL EXECUTIVE 1977-78

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Professor W.D. Williams,
Department of Zoology,
University of Adelaide,
ADELAIDE, S.A. 5001.

NEWS

FROM OUR VICTORIAN BRANCH:

An extremely interesting address was given by Dr. David Mitchell to approximately 30 Victorian ASL members, at Caulfield Institute of Technology, on Wednesday, 9th November.

Dr. Mitchell has recently joined the CSIRO Division of Irrigation Research in Griffith, N.S.W., from Rhodesia where, since 1961, he has been on the staff of the University of Rhodesia at Salisbury. The address, "Principles and Problems of Aquatic Weed Management in Australia", was spiced with well chosen examples of weed problems in both Australia and overseas, particularly Rhodesia.

After Dr. Mitchell's address, a short meeting was held, to ascertain whether Victorian ASL members wished to start up a Victorian branch. This suggestion was well received, and it was decided that during 1978 regular meetings would be held, at 6.30 p.m. at approximately monthly intervals, at the Arthur Rylah Institute.

A.S.L. LIBRARY

The ASL Library contains an assortment of about 1,000 reprints from Australian and overseas authors dating from the late 1940's. The great bulk of material was published between 1965 and 1970.

Various volumes of journals such as Amazoniana, The Japanese Journal of Limnology, etc. are in the collection, but it appears that none of these has been received on a regular basis.

The reprints have been catalogued by author but not as yet by subject. Distribution of a reprint list is probably impracticable due to the number of papers involved. It would be possible, however, to circulate a list of authors or possibly a list of subject classification when the reprints are catalogued by subject.

Mr. K. Shearer is prepared to handle reprint requests if requests are made for a paper by a particular author, but at present it is impossible to find material on a particular subject. Reprints requests should be sent to:

Mr. K. Shearer,
P.O. Box 182,
NARRANDERA, N.S.W. 2700.

Any suggestions on how information on the contents of the Library can be made known would be greatly appreciated and sent to Mr. Shearer.

NEWS FROM SOUTH ISLAND

(1) King and Tyler have named 3 lakes in the Gordon River wilderness area. They are Perched Lake, Sulphide Pool and Gordon Lagoon. The names have been gazetted by the Nomenclature Board, which rejected two other proposals - Lake Olegas and Lake Truchanas - in favour of Lake Difler, after a 1930's forester, and Lake Morrison after a Huon Pine getter.

Three of these lakes are intensely meromictic - Morrison, Fidler and Sulphide Pool - with 15 cm thick chemoclines at about 1.5 m depth, complete with purple sulphur bacteria, interface dwelling microflagellates and migratory chaoborids tolerating high H_2S levels. King's Ph.D. project centres on these lakes.

(2) King and Tyler have taken delivery of a $10,000 Techtum QSM 2500 scanning, integrating quantaspectrometer and underwater housing. As soon as the helicopters start flying again they intend to deploy the instrument. Any suggestions as to what they should do with it or how to use it would be welcome!

(3) Sue Blackburn (Ph.D. student) emerged from her Petri dishes briefly in July. She is investigating geographic extent of genetic compatibility in desmids, including Macquarie Island and New Zealand vis-a-vis Tasmania.

(4) Azizan Baharuddin (Hons. student) is investigating the distribution of calanoid copepods in the State, plus taxonomy of Dinoflagellates and scaly Chryscophyceae by Scanning Electron Microscopy.

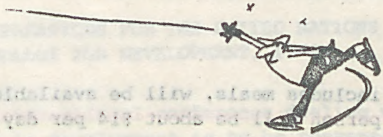
(5) Reappointment of resigning staff members is forbidden in Tasuni at present. As a result of a resignation Tyler now teaches 2/3 of 1st year Botany. The whole of 1977 so far has been given over to preparing new lectures. It is understood he has first hand experience of secondary thickening.

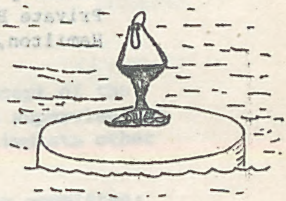
* * * * *

I regret to report that John Lake died in early December.

Editor.

A LITTLE LIMNOLOGICAL KNOWLEDGE WOULD .....





CONFERENCES - RECENT AND NEAR FUTURE

An International Symposium on THE AGRICULTURAL INDUSTRY AND ITS EFFECTS ON WATER QUALITY will be held at Waikato University, Hamilton, N.Z., on 15-18 May, 1979.

TOPICS:

Three major topics will be discussed:

1. Characterisation, Treatment and Disposal of Wastes from Agriculture (including the processing industries).
2. Agricultural land use and its effects on catchment outputs. (Water quality and quantity.)
3. Changes in freshwater systems caused by outputs from agricultural catchments.

It is envisaged that one day will be dedicated to each of the above topics.

ACCOMMODATION:

Accommodation, which includes meals, will be available on the University Campus. The charge per person will be about $14 per day.

Hotel and Motel accommodation will also be available at about $19-21 per two bed unit.

TOUR AND LADIES PROGRAMME:

These will be organized to places of local and specialist interest.

Details will be given in the Second Circular.

PROVISIONAL REGISTRATION AND ALL CORRESPONDENCE:

Those wishing to receive the second circular are asked to return a Registration form by 30th September to:

Dr. C.J. Schouten,
Water and Soil Division,
Ministry of Works and Development,
Private Bag,
Hamilton, New Zealand.

* * * * *

SIXTH AUSTRALASIAN HYDRAULICS AND FLUID MECHANICS CONFERENCE

ORGANISED BY: The Institution of Engineers, Australia

SPONSORED BY: The University of Adelaide
The Australian Academy of Science
The Institution of Engineers, Australia

VENUE: Adelaide, South Australia
5-9 December, 1977

INFORMATION: Registration Form and all enquiries should be directed to:

The Conference Manager,
6th Australasian Hydraulics and Fluid Mechanics Conference,
The Institution of Engineers, Australia,
11 National Circuit, Barton, Australia, 2600.

Telephone: Canberra (062) 73.3633

* * * * *

AUSTRALIAN PREPARATIONS FOR THE UNITED NATIONS CONFERENCE ON SCIENCE AND TECHNOLOGY FOR DEVELOPMENT, 1979

A major international conference dealing with the role of science and technology in development is to be convened by the United Nations in 1979. Where the conference is to be held will be decided by the UN General Assembly later this year.

CONFERENCE OBJECTIVES:

Since 1963, when a large UN scientific conference in Geneva discussed the application of science and technology for the benefit of developing countries, there has been an increasing interest in this question in the UN and other international bodies. Over the past few years there has been intensified debate in the international community about the need to establish a new international economic order to eliminate the growing gap between developed and developing nations by accelerating economic and social development. This north-south dialogue has increasingly recognised the major role that science and technology must play in the process. The problem remains as to the ways and means by which this role can be achieved.

AUSTRALIAN INVOLVEMENT:

The Australian Government strongly supports the concept of the Conference and has established a steering committee to supervise the preparation of the Australian national paper and to stimulate other appropriate activities.

The following bodies are represented on the steering committee: Department of Foreign Affairs, Australian Development Assistance Bureau, Department of Science, Commonwealth Scientific and Industrial Research Organisation, Australian Science and Technology Council.

FURTHER DETAILS:

The Secretary of the Australian Steering Committee,
UN Conference on Science and Technology for Development,
Department of Foregin Affairs,
Administrative Building,
PARKES, A.C.T. 2600. Telephone: (062) 61.3361

The SECOND NATIONAL CONFERENCE OF THE ASIAN STUDIES ASSOCIATION to be held at Sydney in May, 1979, is organising a special Panel on SCIENCE, SCIENTISTS AND TECHNOLOGY IN ASIA. This will provide a forum for scientists, experienced in the development of modern science and technology in Asia, to meet with fellow scientists to discuss the problems they have encountered, and also for interested scientists and Asian Studies specialists to review Australia's role in that development.

The first National Conference of the ASAA, held in Melbourne in August 1976, attracted more than 1,000 participants and highlighted the interest of Australians in Asia. Science, technology and technical education are crucial factors in the change which is now occurring in less developed countries and the ASAA invites scientists to discuss the progress and problems of science and technology in Asia and the Pacific.

AN INVITATION TO PARTICIPATE:

The organisers of the Panel invite scientists and those interested in science and technology in developing countries to submit papers for inclusion in the Second National Conference in May, 1978. Three themes we suggest are:

1. Scientific and Technological Training for the 'Third World'.
2. The Impact of Western Institutional Models on 'Third World' Science Administration.
3. An Appraisal of Australia's Role in Relation to Both Technological Training and Technological Transfer.

The SCIENCE, SCIENTISTS AND TECHNOLOGY IN ASIA Panel is being organised by the members of the School of Science, School of Australian Environmental Studies, School of Modern Asian Studies and Science Policy Research Centre of Griffith University, Brisbane.

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INTERNATIONAL CONFERENCE ON DEVELOPMENTS IN LAND METHODS OF WASTEWATER TREATMENT AND UTILISATION

LOCATION:	The University of Melbourne
SECRETARIAT:	The Melbourne and Metropolitan Board of Works
SPONSOR:	Australian National Committee of the International Association on Water Pollution Research
CO-SPONSORS:	Australian Water and Wastewater Association Asian Regional Division of International Association of Hydraulic Research The Melbourne and Metropolitan Board of Works The University of Melbourne The Commonwealth Scientific and Industrial Research Organisation Division of Chemical Technology
PURPOSE OF THE CONFERENCE:	The use of land for the disposal of domestic, agricultural and industrial wastewater has been practised for many years. Recently, interest in these methods has intensified due to their generally low cost and energy requirements. Developments and investigations are establishing much better understanding of the capabilities and limitations of these methods.

PURPOSE OF THE CONFERENCE: (cont.)

The Melbourne and Metropolitan Board of Works has long-term experience with a variety of low-cost land processes, and investigations are currently being undertaken throughout Australia.

The conference will provide a forum for discussion for those engaged in research concerning such processes and those for whom their adoption would appear appropriate.

* * * * *

NATIONAL WILDERNESS CONFERENCE

A Conference to discuss the stage reached in wilderness conservation in Australia and to work out ways and means of promoting wilderness conservation nationwide in the future.

ORGANISED BY: The Australian Conservation Foundation Inc.

21-23 October, 1977.

* * * * *

AUSTRALIAN WATER AND WASTEWATER ASSOCIATION, SUMMER SCHOOL '78

"Water Quality - Objectives, Management, Achievements and New Horizons"

VENUE: Hobart, Tasmania

6-10 February, 1978

INFORMATION: Mr. B. Healey,
Hon. Secretary,
Summer School, 1978,
Australian Water and Wastewater Association,
P.O. Box 336,
Sandy Bay,
Hobart, Tasmania.

* * * * *

SCIENCE, TECHOLOGY AND PUBLIC POLICY: AN INTERNATIONAL PERSPECTIVE

A Conference arranged by the University of New South Wales and the New South Wales Division of ANZAAS.

VENUE: Sydney, New South Wales

1-2 December, 1977

INFORMATION: Mrs. N. Allen,
Conference Secretary,
School of History and Philosophy of Science,
The University of New South Wales,
P.O. Box 1,
KENSINGTON, N.S.W. 2033.

* * * * *

SECOND EXECUTIVE COMMITTEE MEETING

Monday, 19 September, 1977, Melbourne

MINUTES

Present: D. Buckmaster (Chairman), J. Barclay, A. Fletcher, R. Williams, B. Hart, I. Campbell (by invitation).

Matters arising from Minutes of previous meeting:

1. Project Aqua. I. Campbell reported that he had prepared and submitted the Society's lists of unique sites to the National Heritage Commission. It is believed that all sites have been accepted by the National Heritage Commission. A list of these sites is to be published in the next Newsletter, with a request for members believing there are other sites worthy of consideration to forward the details to I. Campbell.

2. Policy Statement re Publication in Newsletter. The Winter Newsletter contains an Editorial, in which the policy is stated.

3. Consulting. After considerable debate on this matter at the A.G.M., Drs. Yezdani and Pollard agreed to prepare discussion papers for publication in the Newsletter and comment by members. Secretary to write to Yezdani and Pollard, reminding them of their commitment, and requesting their contributions as soon as possible.

4. Education Sub-committee. Secretary reported that Jeff. Clark had been contacted regarding this sub-committee, and a reply had been received from him, indicating that he was actively soliciting members and views through letter and, hopefully, through a letter to be published in the Winter Newsletter.

5. Constitution. Dr. Pollard agreed at the A.G.M. to prepare a draft of necessary changes to the Constitution for consideration by the committee. Secretary to write to Dr. Pollard.

6. Cooloola Area Conservation Committee. Secretary reported that he had replied to the Cooloola Committee, stating the A.S.L. policy on conservation issues.

7. Jolly Award.

   (a) There was a brief discussion on the details of the Jolly Award selection committee membership, and it was decided that little progress could be made until more background detail was available. Secretary agreed to provide such detail at the next Executive meeting.

   (b) Secretary/Treasurer reported that the ANZ bank do not have investment accounts for less than $500 fixed deposit. The committee instructed the Secretary/Treasurer to deposit $500 in the Jolly Award Account.

8. 17th Congress. D. Buckmaster reported that he had made preliminary contact with L. Llewellyn, N.S.W. State Fisheries, regarding the possibility of the next Congress being at Menindee. There was general support from the committee for this venue, and D. Buckmaster agreed to contact Dr. Llewellyn again in the very near future. He agreed to report back to the next committee meeting.

9. A.G.M. Controversial Issues.

(a) The committee requested that the Secretary contact Prof. Williams, regarding a short reminder in the next Newsletter - that any member wishing to bring up a major controversial issue for discussion at the next A.G.M. should prepare a short discussion paper for publication in the Pre-Conference Newsletter.

(b) Committee felt the Pre-Conference Newsletter could well contain a short request, asking members wishing to put forward a venue for the 18th Congress to prepare a brief note, outlining details and advantages of the Conference being at their particular venue.

Membership:

(a) The Secretary/Treasurer reported that the 1977/78 subscription rates were $8.00 for members and $4.00 for students. The CSIRO have advised that the 1978 subscription to the Australian Journal for Marine and Freshwater Research will be $7.50 for A.S.L. members.

(b) The Secretary/Treasurer reminded the committee that there was a need in the near future for an updated version of the membership directory.

(c) The Secretary/Treasurer reported that an additional 22 persons have joined ASL since the Lismore Conference in May.

Treasurer's Report:

(a) General Account

Income		Expenditure	
Transfer from S.A.	$536.43	A.P.E.C.	$52.03
Receipts to 5.9.77	379.67*	Rank-Xerox (Newsletter covers)	80.06
Interest	18.16	Bank Charge	0.69
TOTAL	$934.26	TOTAL	$132.78
		Balance - Credit	$801.48

*Additional $169.50 yet to be paid in.

(b) Publications Account

No transactions since A.G.M.

Balance (Credit) - at A.G.M. - $2,108.21

(c) Jolly Award Account

Balance (Credit) - $131.07

TOTAL CREDIT BALANCE IN ALL ACCOUNTS - $3.046,76

Treasurer to check the Constitution regarding the running of two accounts - the General Account and the Publications Account. This would be with a view towards closing the Publications Account and working only with the General Account.

Establishment of a Victorian section of A.S.L.:

Considerable discussion ensued on this point, and it was agreed with enthusiasm that such a move should be attempted. It was decided that a first meeting of those interested would take place in the near future in Melbourne, at which a well recognised speaker (suggestions:- David Mitchell, aquatic plants) be invited. It was also suggested that the meeting be publicised, either by an article in the Newsletter or by a special insert placed in the next Newsletter.

General Business:

Library: Committee members expressed the view that few A.S.L. members either knew of the existence of the A.S.L. Library at Narrandera, or, if they did know of its existence, had little idea of what was contained in the collection. It was agreed that the Secretary/Treasurer write to Karl Shearer, suggesting that he consider writing a short article for publication in the next Newsletter, outlining what is contained in the A.S.L. Library and how people can use documents.

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ADVANCE NOTICE OF THE SEVENTEENTH ANNUAL CONGRESS

The Executive Committee is currently finalising the venue and format of our next Congress in May 1978. This function will definitely be a live-out affair, remote from the trappings of suburbia. Members interested in attending are requested to read the enclosed notice carefully and return the questionnaire to the relevant address as soon as possible. Further details will be forwarded with the next issue of the Newsletter.

A NOTE TO THE EDITOR FROM THE SECRETARY/TREASURER

Please find enclosed a copy of the minutes of the second executive committee meeting held in Melbourne on the 19th September, 1977. I direct your attention to item 9 - A.G.M. controversial issues. Apparently there was some discussion on major controversial issues for which A.S.L. support was sought. My understanding is that members felt that those wishing to raise such issues should prepare a short discussion paper for publication in the pre-conference newsletter. Accordingly, you might pencil out a short reminder to such people for publication in the next newsletter. [This is it.]

Also the executive committee briefly discussed the question of the venue for the 19th A.S.L. congress in 1979. There was some feeling that it would perhaps be advantageous for those persons or groups wishing to put forward a venue to prepare a brief outline of the advantages, facilities, etc. if the conference was held at their particular spot. Again I would be most grateful if you could insert an appropriate short paragraph on this in the next newsletter. [This is it.]

I hesitate to make the above requests of you since I know that you have an extremely tight schedule. If in the future you would prefer that I wrote an appropriate passage for direct insert into the newsletter, please don't hesitate to inform me. I can assure you that when I receive the letter I will treat it accordingly by screwing it up and disposing of it in the waste paper bin.

* * * * *

AQUIFERS OF THE MURRUMBIDGEE FLOODPLAIN - PRELIMINARY RESEARCH

by W. HOLLAND*, K.G. McKENZIE*, A.J. JORDAN*

(*School of Applied Science,
Riverina College of Advanced Education,
Wagga Wagga, N.S.W., 2650.)

The Murrumbidgee System is a composite water resource, comprising surface river waters, billabongs and lakes, extensive impoundments, irrigation channels, and a vast and largely uncharted body of groundwaters. It is one of the country's most valuable remaining primary assets, bearing in mind the aridity of most of Australia and the deterioration of the Murray. It services the Murrumbidgee Irrigation Authority and its catchment includes the sites for some of the series of dams which make up the Snowy Mountain Hydroelectric Authority and provide power to the eastern States. The value of its groundwaters (aquifers) is not widely appreciated but Table I, which lists aquifer usage around Wagga Wagga, New South Wales, gives some measure of the scale of present daily utilisation.

The Murrumbidgee aquifer system is highly complex, with upper, usually unconfined Quaternary aquifers overlying a lower Tertiary system. The Tertiary system contains several interconnected confined aquifers at varying depths (Woolley, 1972).

The floodplain of the Murrumbidgee is characterised by polymict gravels in the upper layers with sand beneath them. Gravel, sand and clay beds underlie this layer of sand. This report deals specifically with the area between Oura and Wagga Wagga (Figure 1) but similar lithologies extend westwards and have been correlated with sequences in Victoria in a recent report (Woolley and Williams, 1977).

Over most of the floodplain, the bedrock is Devonian granite but in some places it consists of slates, phyllites and weakly schistose rocks which represent metamorphosed Ordovician sediments. This bedrock varies in depth from about 175 m below topographic level at Narrandera to about 75 m below topographic level at Pomingalarna just west of Wagga Wagga.

TABLE 1. Usage of groundwater resources around Wagga Wagga

	Delivery Rate	Location
1.	315,000 galls/hr	Gumly Gumly bores for Northern Riverina County Council (NRCC)
2.	8,000 galls/hr	Holbrook 1
3.	4,000 galls/hr	Holbrook 2
4.	55,000 galls/hr	Kooringal Rd EW1) 118,000 galls/hr when linked
5.	67,000 galls/hr	Kooringal Rd EW2)
6.	125,000 galls/hr	N. Wagga
7.	83,000 galls/hr	E. Wagga
8.	60,000 galls/hr	W. Wagga - projected capacity of system 300,000 galls/hr
9.	400 galls/hr	Mangoplah
10.	2,000 galls/hr	Humula
11.	4,000 galls/hr	Tarcutta
12.	1,200 galls/hr	Woomargama

Notes: Bores 2-12 service the Southern Riverina County Council (SRCC) district.

Total delivery from around Wagga for deep bores (1-10) is over 17 million gallons per day (about 77.5 million litres per day). Bores 11 and 12 are shallow bores.

Data from SRCC Engineers Department.

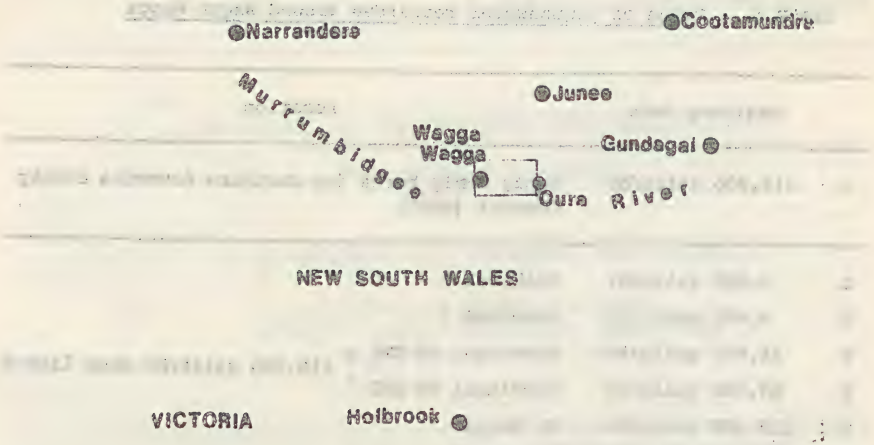

FIGURE 1. The Murrumbidgee River between Gundagai and Narrandera, New South Wales, indicating the study area (hachured).

The major aquifer in the Quaternary deposits lies in thick coarse conglomerates at 6-25 m below the floodplain. So widespread is this shallow aquifer that most local stock and domestic wells draw their water from it (Whiting, 1945). Around Wagga Wagga, maximum yields approximate 45,000 litres per hour although bores have been capable of delivering many times this amount. The upstream limit of these high discharges lies near Oura about 16 km to the east of Wagga Wagga.

Tritium analyses, plus water table contours, confirm recharge of the Quaternary aquifers by the Murrumbidgee River when it is high (Barnes and Carswell, 1973). Meteoric water may be a minor contributor. The reverse can also occur, with aquifers recharging the river, in times of low river level. This close synchronisation indicates that the shallow aquifers are highly permeable.

The underlying Tertiary sequence is composed of grey quartzose sand and gravel, intercalated with grey and blackish clay bands which are often carbonaceous and also contain rare pyrite and wood fragments. Few bores have penetrated the full thickness of potential water bearing strata. At Gundagai, the bores deliver approximately 22,5000 litres per hour from this aquifer system but this is commonly exceeded around Wagga Wagga where total delivery from deep bores - operated by or on behalf of the Northern Riverina and Southern Riverina County Councils - amounts to over 77 million litres per day (Table 1). There has been no significant variation in water level in the bores since usage commenced. These excellent yields, which imply easy movement of water through the aquifers, result from better sorting of the Tertiary sediments as well as thickened sequences of reservoir rocks which date back at least to the late Tertiary (Martin, 1973).

Field and laboratory methods

Over 100 bores and wells were sampled during 1976-1977 as part of a student science project, particular care being taken to minimise contamination. Since official locality data frequently proved inaccurate, sample locations were plotted as precisely as possible on air photographs and then transferred to a composite map. For each sample, information on depth and standardised delivery rates were incorporated when available.

Standard techniques (see, for example, Reinson, 1974) were employed in the chemical analysis of samples. These included direct metering, electrometric titration and atomic absorption spectrophotometry. Sulphate ion was determined by difference first and the results then checked, for 10 samples, against SO_4 as found by barium chloride precipitation. Using cation and anion balances, percentage errors for these 10 analyses ranged from -4.3% (mean -2.3%) to +3.2% (mean +1.6%). This indicates a high accuracy for the complete chemical analyses. As a further check, the ratio of total dissolved solids to specific conductance was calculated for all samples. The values lie between 0.60-0.71. This is well within the range for waters of ordinary composition, which is 0.55-0.75 according to Reinson (op. cit).

Copies of the original data on which this report is based can be obtained from the authors.

Results and Conclusions

The theoretical basis for understanding the development of the Murrumbidgee System has been proposed in considerable detail (e.g. Schumm, 1968 and references therein) except that not much attention has been paid to the qualities of the various subsurface waters which it contains.

The chemical characteristics of waters sampled by us conform to those of most Australian inland waters (Williams and Hang Fong Wan, 1972) as far as the order of cation dominance is concerned, with Na > Mg > Ca > K, unlike world fresh water (Figure 2), but the order of anion dominance is less clear in that many samples are dominated by each of the three major anions.

According to Gibbs (1970), three main mechanisms control the chemistry of the world's surface waters: atmospheric precipitation; rock dominance; and evaporation - crystallisation. We re-emphasise that our samples lie well within the range of natural surface waters in their overall chemistry. In effect, the aquifers in our study area are fossil natural surface waters since they were unaffected by the Teriary marine incursions which influenced some subsurface waters to the west (Pels, 1969).

Following criteria established by Gibbs (op. cit.), the high Na content of most Tertiary samples suggests an origin from atmospheric precipitation whereas their high HCO_3 content probably derives from weathering of local rock and soil. We conclude that these waters originated from a combination of atmospheric precipitation and weathering during the Tertiary developmental history of the floodplain. Their generally good quality is corroborated by the fact that they now service whole townships, e.g. Junee, Cootamundra, Wagga Wagga itself. Usually, they are low Cl waters, often high in HCO_3 or occasionally high in SO_4. The cations seem to be balanced or else to favour Na and K with one exception which has a high proportion of Ca and Mg (Figure 2).

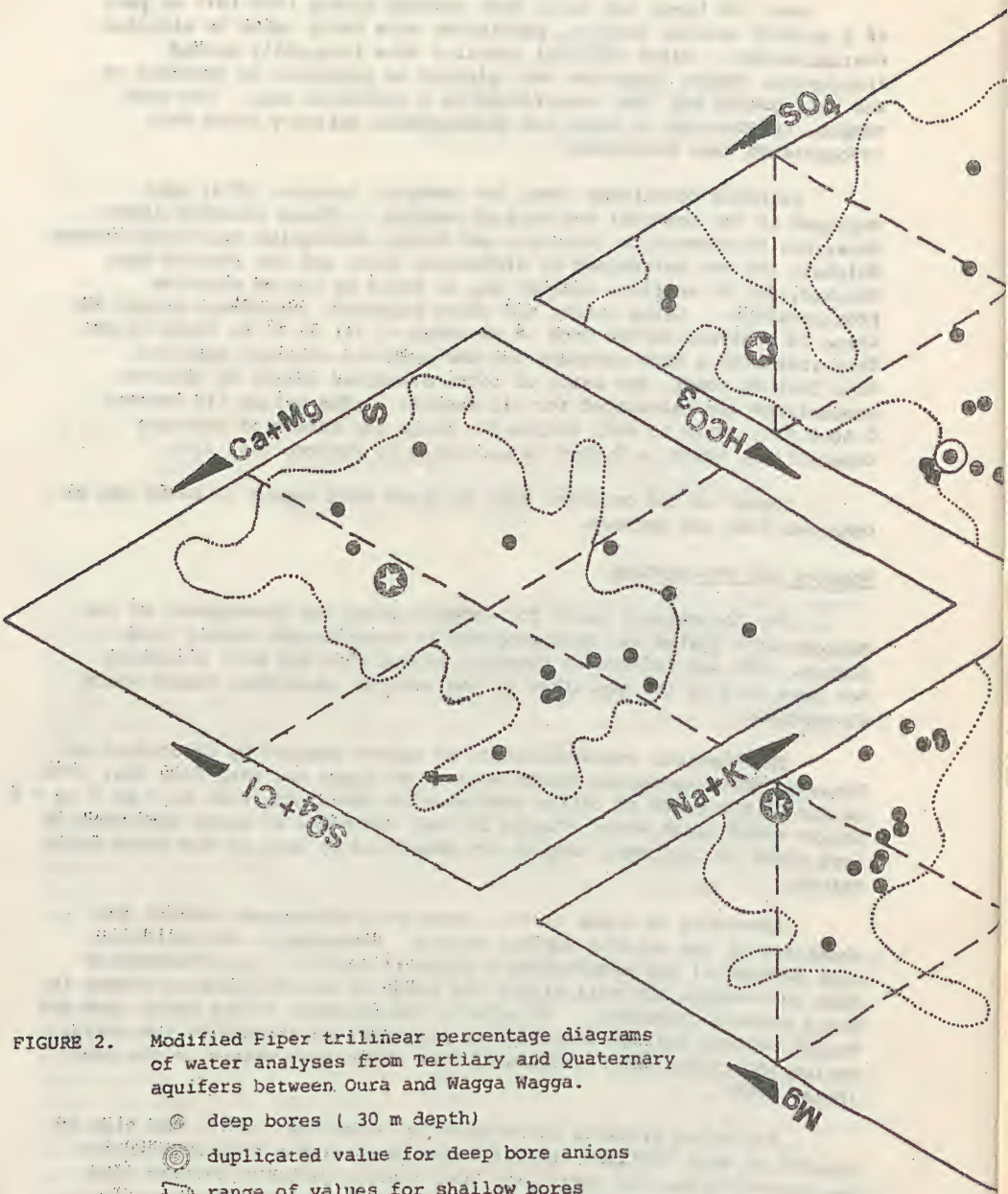

FIGURE 2. Modified Piper trilinear percentage diagrams of water analyses from Tertiary and Quaternary aquifers between Oura and Wagga Wagga.

- deep bores (30 m depth)
- duplicated value for deep bore anions
- range of values for shallow bores
- Murrumbidgee River
- S World sea water
- f World fresh water
- 50% lines

Waters from the Quaternary aquifers are highly variable in quality (Figure 2); this depending upon the relative positions of bores along the valley length as well as their distance from the Murrumbidgee. Upstream from Wagga Wagga, this water is suitable for most irrigation uses whereas downstream salinity increases progressively and is too great for irrigation except at locations close to the river. The Quaternary aquifers probably include several confined lenses which originated by evaporation - crystallisation since some samples approach sea water in composition. We class these saline waters as athalassic (Bayly and Williams, 1966; Bayly, 1967). Many Quaternary bores, however, deliver potable water and, because of the high costs involved in drilling deep bores to reach the Tertiary strata, it is desirable economically to develop some technique for predicting whether proposed shallow bores in the district will strike salty or fresh water.

To conclude, this report serves as notice that we intend to develop a data base of detailed analyses of existing bores and wells in both the Tertiary and Quaternary aquifers of the Murrumbidgee floodplain. We propose to concentrate initially on the area between Gundagai and Narrandera because our laboratories are situated here, because aquifer water quality falls off below Narrandera and because the best deliveries to date have been obtained over this part of the floodplain, notably near Wagga Wagga (Table 1). From this data base, more knowledgeable decisions can be made on the management of regional water resources, with regard to both quantity and quality, in order to maintain community life styles and promote regional developments.

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THE DEMISE OF TAYLORS LAKE

By B.V. TIMMS

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On a field trip during the XVIth Congress at Lismore, May 1977, a number of us examined Taylors Lake, 6 km south of Byron Bay. At the time I briefly explained the present condition of the lake and postulated on its recent history. I intend now to document this information in some detail.

Taylors Lake lies impounded behind a frontal dune, is about one hectare in area and receives inflows from swamps behind it and to the north. There is a wide opening to the ocean and during spring high tides sea water enters. At the same time beach sand is washed in, so much so, that the lake has recently been divided into two.

Much of the lake is about a metre deep and lined with a variety of littoral plants including *Cyperus laevigatus*, *Juncus kraussi*, *Scirpus validus*, *Sporobolus* sp., and *Phragmites australis*. The Mangrove Fern, *Acrostrichum speciosum* grows sparsely near the oceanic entrance and also in the swamp inland from the lake. Water is brackish averaging around 5‰, is darkly stained and somewhat acid (mean pH = 6.0). Two species of zooplankter live in the lake - *Gladioferens spinosus* and *Sulcanus conflictus*, both common estuarine copepods. The littoral fauna is depauperate and consists of a curious mixture of marine and freshwater species. There are juvenile prawns (*Metapenaeus* sp.), a species of sphaeromidid isopod, two species of snails (*Posticobia brazieri* and *Tatea keseveni*) and a bivalve (*Fluviolanatus amarus*). Freshwater species include two kinds of odonate nymphs (*Ischnura heterostricta* and *Pseudagrion ? microcephalum*) and a water strider.

A lake with these characteristics is not particularly special for such a habitat is repeated time and again along the eastern and southern coastline of Australia. Yet Taylors lake is of interest because there is

good reason for believing that it has changed in recent years as a result of man's activities in the area.

The frontal dune separating the lake from the ocean was mined for mineral sands in 1960, 1963 and again in 1965-66. It has since been stabilized and revegetated, but it is eroding, particularly around the entrance to the lake. The lake itself was not mined. From interviewing four people who have known the lake for many years and in addition to drawing on my boyhood experience of the area, I concluded that before 1960 the lake was much deeper (to 3 m?), grew waterlilies and was either permanently fresh and closed (according to three people) or brackish with a small channel through the dunes to the sea (according to two people). I will consider both possibilities.

If the lake was fresh before 1960 then it would have had the characteristics of dune lakes of the sandy coastal lowlands of eastern Australia. These have been studied by Ian Bayly and others and are best represented on the sandy offshore islands of southern Queensland, e.g. Fraser Is. There are perhaps four typical examples along the N.S.W. coastline.

Most of these dune lakes are perched above the general water table and lie in dune hollows scooped out by wind action but partly filled with organic matter washed and leached from the surrounding slopes. This forms a seal and hence a localised water table and perhaps free standing water. Such water is very acid (pH 4.5 - 6.0), discoloured by humic matter and of low salinity (<50 ppm). There is very little phytoplankton in such lakes but an abundant zooplankton which typically consists of one species - the copepod *Calamoecia tasmanica*. It seems that the planktonic food chain is based on bacteria which utilize the carbon in humic matter. If so, then this is academically exciting, and who knows may have a commercial application in the centuries to come. Additional interest centres around the fish and littoral invertebrate fauna.

In that Taylors Lake is at or was only just higher than sea level, is impounded behind a frontal dune and is not in extensive sandy lowlands, it would not have had all of the above features. Most likely it was similar to the present Lake Ainsworth, a few kilometres to the south. This lake is about 10 m deep, a little above sea level, with acid (pH = 5.0) humic water, but the latter is not as fresh as usual (TDS = 100 ppm). *Calamoecia tasmanica* is the only zooplankter but the littoral flora and fauna is somewhat different as my present investigations are revealing. It certainly does not harbour the littoral plants, the estuarine copepods or the molluscs now found in Taylors Lake.

In considering the second possibility, namely that the lake has always been brackish, there is some further supporting evidence, but also an anomaly. The mangrove fern *Acrostichum speciosum* almost always grows in brackish water and the presence of some large clumps near the lake's entrance strongly suggests the lake has been brackish for many years, certainly predating mining. The anomaly is the pre-mining occurrence of water lilies in the lake; these can only grow in fresh water. So either the lake was completely freshwater [it might be pointed out that the mangrove fern has once been recorded from fresh water (M. Tindale, personal communication), so a fresh water past is not precluded]; was intermittently fresh or there was a salinity gradient with the lake being mainly fresh, but brackish near the entrance where the mangrove fern grows.

Most coastal lagoons along the N.S.W. coastline connected to the sea contain sea water with a salinity gradient far removed up some inflowing stream or non-existent. There are not many with fresh or slightly brackish water; the Myall Lakes system is one example and, on a smaller scale, so is Blue Lagoon in the Red Rock National Park north of Coffs Harbour. Blue Lagoon is about the same size as Taylors Lake, is fresh but has a steep salinity gradient along a narrow channel to the beach. If Taylors Lake had been brackish in the past, its regime would have been similar to this.

By comparison with Blue Lagoon the dominant plants in Taylors Lake would have been *Phragmites australis*, *Typha* sp., *Scirpus* sp., and *Chara* sp., zooplankton and benthos would have been sparse, and among numerous invertebrates three species of snail and a bivalve (*Fluviolanatus amarus*) would have been present. Most of these would have been exterminated with the change in salinity regime but some (*Phragmites* and the bivalve) have lived on and a few extra species added.

I am sure that one or other of these two regimes once applied to Taylors Lake; personally I think the lake was fresh, but admittedly the evidence is not conclusive. Both regimes are more interesting ecologically and relatively unusual habitats compared to the present condition. Closed freshwater lakes impounded behind frontal dunes are uncommon and slightly different from perched dune lakes in the characteristics. The best example in N.S.W., Lake Ainsworth, is somewhat adversely affected by recreational usage, so further examples would be desirable. The other habitat type is even rarer and the best extant example, Blue Lagoon, may have its frontal dune mined even though it is within a National Park.

Unfortunately it is too late to save Taylors Lake and to do much about Ainsworth, but Blue Lagoon can be left pristine. At the worse, precautions should be taken during mining so that there is no interference with the outflowing creek or lake edge; at best, the decision to mine the frontal dune should be revoked. Recently the Wran Government announced that there would be no mining in the Red Rock National Park, among other coastal parks, but the Opposition said it would reverse the decision when returned to power. May the environmental value of Blue Lagoon outweight political pettiness.

Acknowledgements

I wish to thank the staffs of the National Herbarium and the Australian Museum in Sydney and Dr. J.A.L. Watson of CSIRO Canberra for their identifications and Mr. Russ Maslin of Mullumbimby for his field assistance and for arranging interviews with local people.

* * * * *

LIMNOLOGISTS ENTER THE SPACE AGE

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Introduction

The water pollution control law passed by the United States Congress in 1972 calls for, among other things, areawide planning for water quality management. In the State of Michigan this task was given to the fourteen sub-state regional planning councils. The Southcentral Michigan Planning Council (S.M.P.C.) area consists of five countries, covering about 7,700 square kilometres. Within this area there are over 1,000 bodies of surface water, including nearly 300 which have substantial residential development. Most of these are in rural areas where there may be direct competition with agricultural interests for the use of both land and water. Even in urban areas, the interests of lake residents often conflict with other development needs such as storm drainage, industrialization and public access to the lakes.

Many lakes and ponds in the area have developed serious water quality problems. A few of these lakes have been studied intensively over a long period of time, but there was little or no information about most of them. In this management planning program it was necessary to assess the water quality in a large number of lakes, within a period of 18 months, and with a limited budget. Some form of remote sensing appeared to be the only reasonable alternative, since a traditional water sampling and analysis program could have covered only a few of the lakes.

Dr. Wood, under contract to S.M.P.C., worked first with the Aerospace Division of the Bendix Corporation at Ann Arbor, Michigan, and later with Purdue University's Laboratory for Applications of Remote Sensing (L.A.R.S.) at W. Lafayette, Indiana, to explore methods for classifying the waters of inland lakes according to content of color-giving materials such as phytoplankton, zooplankton, tannins, and silt. The most useful technique was developed in conjunction with L.A.R.S.

Data Collection

The data are gathered by the National Aeronautics and Space Administration (N.A.S.A.) Landsat satellite which passes over a given point on the Earth every eighteenth day. It is equipped with sensors which detect in the light reflected back from the Earth, the intensities of four different wavelengths in the electromagnetic spectrum. L.A.R.S. purchases the data, which are stored on computer tapes. Their computer is programmed to separate as many spectral classes which can be equated

to categories of water and wetlands as possible, given certain limits of statistical overlap among the categories. The computer output (see Figure 1) looks like a map of a lake, made up of various typewriter symbols, each representing an area of 0.44 hectare. In the data for 1973, 11 categories were distinguished; in the 1976 data, 13 categories were found. Dr. Wood used his knowledge of area lakes, along with published reports, to determine what many of the categories represented. Ground-truthing field work was conducted at the time of the 1976 satellite passage to verify water classes. Since the system relies on differences in colour to distinguish among the water classes and water classes exist as intergrades, a perfect match between spectral and water classes is not always achievable. Local knowledge must be used to determine which water classes were actually present. The computer output shows the distribution of identified classes.

The system, in its current state of development, is limited in its usefulness. Many factors combine to determine the spectral characteristics of the water at the time the imagery is recorded. In the attempt to group these factors, allowing for less than five per cent overlap, it is inevitable that there will be some situations where the imagery may be misleading. For example, two very different aquatic plant types may have similar spectral characteristics. This is not the fault of the imagery or the system, but, rather, an indication that the classification method is less than perfect. So far, it has been necessary to rely on indirect evidence for indications of turbidity. There is hope that a more reliable means of determining turbidity from the satellite imagery can be developed. However, since this technique relies wholly on characteristics of the light reflected from the lakes, there are some features, such as content of nutrients and chemicals, that probably cannot be directly studied by this method. The imagery indicates the dominant feature of the water, not everything it contains. Further, the imagery can only include evidence of what is contained in the layer of water penetrated by light. This factor is especially important when considering deep or turbid lakes.

Data Interpretation

The Landsat data were used to estimate the degree of eutrophication of the various lakes and to assist in determining whether the eutrophication found was natural or cultural. All available information was evaluated to determine the natural characteristics of the lake. In particular, depth, area and extent of shallow water, bottom type and any chemical data which would give insight into the degree of natural eutrophication were examined. The interpreter assumed that natural eutrophication would result in a heterogeneous pattern of water classes, while cultural eutrophication would lead to large homogeneous areas of algal dominance. Where other evidence indicated that natural eutrophication was unlikely, the appearance of large areas of either algal or macrophyte dominance was interpreted as probable cultural eutrophication. Under circumstances which indicated that natural eutrophication existed, the presence of macrophyte growth without large areas of algal dominance and with open clear water areas was deemed as normal and not indicative of a problem.

Uses of Satellite Imagery of Lakes

The examination of the satellite imagery for the lakes of south-central Michigan provided valuable information which was used in determining which lakes had the most severe eutrophication problems. Lakes which were

found to be culturally, rather than naturally, eutrophic were thought to be more likely to be improved by management practices. When allocating the limited funds available for lake water quality improvement projects the question of whether tax monies should be used to alter natural eutrophication must be considered. Many feel that preference must be given to lakes where excessive nutrient loading from human activities can be demonstrated.

Satellite imagery of lakes is most useful as a comparative tool. Images of one lake from two different years, or as different seasons of the same year, can be studied to see what changes have occurred. Neighbouring lakes can be compared to see how they differ. It has also been a very effective public education technique. Riparians are eager to see the satellite "picture" of their lake and from that beginning it is relatively easy to get them interested in water quality and how to improve it. Satellite imagery may also be used by professional limnologists in choosing which lakes to study by more traditional methods.

An Example

Palmer Lake is known to area residents as a lake in need of restoration if it is to continue to be an asset to the area and usable for boating and certain other forms of recreation.

The printouts for Palmer Lake are shown in Figure 1. A key to the category each symbol is thought to represent is shown in Table 1. Dr. Wood's interpretation of the printouts follows:

> "Palmer Lake is severely eutrophic showing a strong tendency toward algal blooms. This lake has a large amount of shallow, marshy area with vast areas of both emergent and submerged macrophytes in both 1973 and 1976. The deeper portions of the lake contain heavy concentrations of green algae in 1973 with blue-green populations around the warmer marginal areas. In 1976 during July the picture is much the same with blue-greens substantially replacing greens as the water warms. The 1976 scene also shows a significant extension of the submerged aquatic beds, probably due to the later date.
>
> In summary, Palmer Lake is a naturally shallow eutrophic lake which now has nutrient levels well beyond what it can handle. Palmer Lake should be classed as a priority problem lake."

Summary

The assessment of lake water quality through the use of Landsat satellite imagery has been shown to be feasible, although further refinements in data input and interpretation are needed. The technique is especially useful when a general survey of a large number of bodies of water is required. It is a valuable tool for communicating with the general public.

TABLE 1. Landsat Satellite Imagery

Key to Symbols

1973 Symbols	1976 Symbols	Class	Key
M	I	Water-9	Clear Water
Absent*	H	Water-8	Diatoms, Desmids, Discolouration
X + O**	G	Water-7	Submerged Narrow-leafed Aquatics (plus unknown**)
T	F	Water-6	Blue-Green Algae
L	E	Water-5	Zooplankton
I	D	Water-4	Blue-Green Algae
Absent	C	Water-3	Broad-leafed Submerged Aquatics & Detritus
/	B	Water-2	Green Algae
=	A	Water-1	Loam Silt
.	-	Wetlands-3	Broad-leafed Emergent - Water Lilies
Absent	=	Wetlands-2	Narrow-leafed Emergent - Grasses
-	/	Wetlands-1	Swampland - Trees and Brush
=	M	Marl	Marl
	*	Clouds	Clouds

* The organisation by water class is based on the 1976 data; therefore, where a corresponding class does not appear in 1973 the word absent appears.

** Two separable spectral classes are included in water class 7 because of our inability to precisely distinguish among the dominant features indicated in the two classes. One of them corresponds to water class 3; elements of water class 8 also appear, in the form of tannin discolouration.

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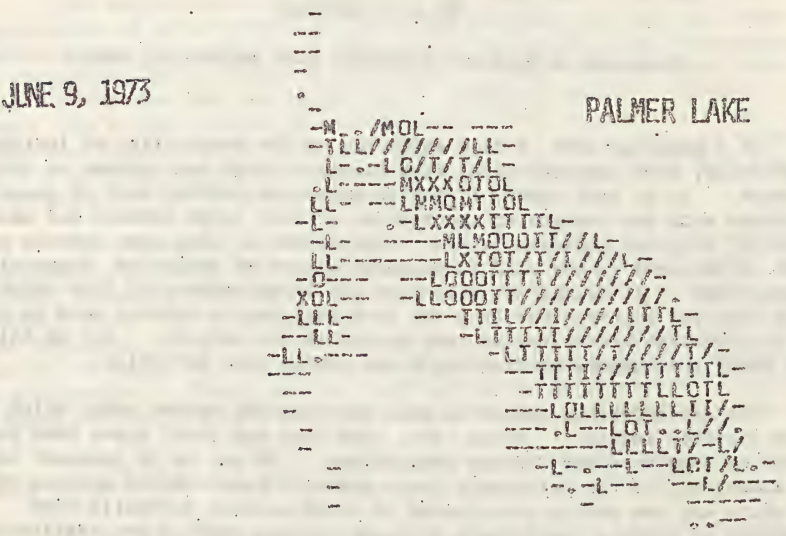
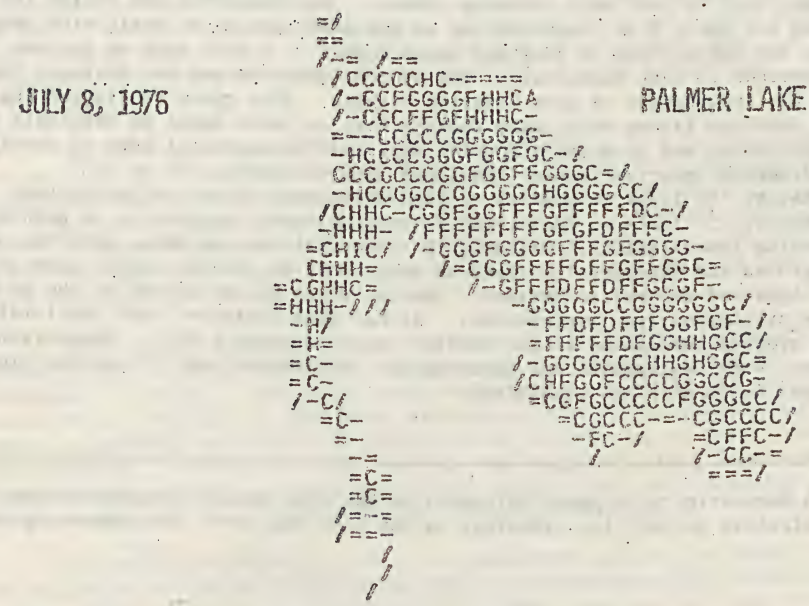
Figure 1 SATELLITE IMAGERY OF PALMER LAKE, ST. JOSEPH COUNTY, MICHIGAN. See Table 1 for key to symbols.





THE THREAT OF INTRODUCED AQUARIUM FISHES TO NORTHERN WATERS OF AUSTRALIA*

By J.C. WHARTON

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In a paper of 1962, I drew attention to the possibility of introducing to Australia, with aquarium fish, fish diseases which are unknown on this continent. In my talk today, I want to emphasise another sort of danger associated with the continuing importation of very large numbers and many species of tropical aquarium fishes. The danger is that many species will become established in the wild in northern waters of Australia, especially in Queensland. It arises not only from the large numbers of fish which are coming into the country, but from the fact that exotic species seem to be able to establish themselves so very easily in our waters. Let me talk first about the numbers of fish which are coming into Australia.

Perhaps reference should be made first to the system under which fish may be imported legally. Since 1947, live fish and their spawn have been prohibited imports under Customs Regulations. It may be of interest to note that almost all of the relatively large and well-known exotic species of fish which are now widely distributed in south-eastern Australia were introduced by private individuals or organisations such as Acclimatisation Societies well before this time. Despite the prohibition of 1947, no really serious effort was made to exercise any positive control over the importation of exotic fishes until the early 1960's, when the Commonwealth/States Fisheries Conference (a fairly regular meeting of persons responsible for Fisheries in the States and the Commonwealth) set up two Advisory Committees to deal with incoming fishes. One Committee was called the Food and Sport Fish Committee and as the name implies it dealt with proposals for the importation of food and sport fishes. I will make no further reference to that Committee. The second Committee was the Advisory Committee on the Importation of Live Aquarium Fishes. This group considered the range of aquarium fishes which they thought then or later might be available for importation and produced a booklet entitled "Alphabetical List of Exotic and Indigenous Aquarium Fishes Classified Into Categories 'A' to 'D'". Category 'A' lists 26 species of fish whose importation is prohibited: Category 'C' lists an additional 87 species whose importation is prohibited pending investigation: Category 'B' lists 604 species whose importation is approved and Category 'D' lists an additional 40 species whose importation is approved subject to review. Species which do not appear in the booklet are prohibited from importation. It has been estimated that the total number of species not listed in the booklet would be about 6,000. Summarising then, some 644 species are approved for importation and 113 species plus about 6,000 more are prohibited.

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* A manuscript of a paper delivered at the 16th Annual Congress of the Australian Society for Limnology on the 21st May, 1977, at Lismore, N.S.W.

The Minister for Customs agreed in principle to the adoption of the Committee's list as a basis for exercising control over the importation of aquarium fish and it is still used today.

The major reason for setting up the Committee to review the importation of exotic aquarium fishes was probably the fact that the numbers of fishes coming into the country for the aquarium trade was, in the early 1960's, becoming very large. Prior to this time, most fish came by boat and the numbers were relatively small. In the early 1960's fish started to come by air, and the numbers involved have been steadily increasing annually. Today, the Australian Trade is a very large one and the total number of fishes imported each year is probably of the order of 10 million.

The responsibility of ensuring that fishes arriving in Australia are healthy and that they are species which are permitted to enter the country belongs with Commonwealth Departments of Health and Customs respectively. In Victoria, and in some other States, this responsibility was delegated to the State Fishery Agency some years ago and for a short period, at least in Victoria, we attempted to examine fishes arriving at Tullamarine. There were no staff and no funds specifically for this purpose and in 1974 we abandoned the operation as being impractical.

Let me give you some insight into what is really required in order effectively to inspect fishes arriving at Tullamarine.

In 1974 (the last year for which we have good data) fish generally arrived from overseas on two days of the week. On each day, we might have as many as 30,000 fish in 150 plastic bags. "Inspection" (when undertaken) involved simply lifting each plastic bag to the light and examining the contents. There may be 1,000 or more small fishes in the bag and although only one species is supposed to be in each container it was not uncommon to find another two unlisted species, perhaps represented by one or two fishes only in each bag. Fish may be so small that positive identification is not possible either because adult features have not developed or because to do so would call for the use of a binocular microscope.

Positive identification of all species of fish in a shipment is not possible. There are too many fish, some are too small and recognition by the average aquarium inspector of at least the 600 odd species which are approved for importation is quite beyond reason. Present members of the Advisory Committe on the Importation of Live Aquarium Fish feel that it is not unreasonable to expect that an aquarium fish inspector should be able to recognize perhaps 100 species of fish.

What are the consequences in Victoria of ineffective inspection at the airport? One result is that there is in the aquarium trade in Melbourne at least 13 species of fish which have been prohibited imports since 1963. Another is the known presence of piranha in the aquarium trade. Recently an officer of the Division was able to purchase piranhas at $3 a head. The identity of the fish was confirmed by Dr. Paxton of the Australian Museum. Other prohibited species such as Tilapia are also fairly common not only in Victoria but throughout Australia.

Although a significant number of prohibited species are known to be available in Melbourne the chances of any of them becoming established in the wild in this State is quite small because they are all warm water

fishes. The sorts of cold water aquarium fishes which are imported sometimes in large numbers are already well established in Victoria in the wild.

The real areas of risk are of course northern New South Wales, Queensland, Northern Territory and the north of Western Australia. The number of aquarium fishes arriving each year at Darwin is not known but arrivals in Sydney exceed those in Melbourne. The number arriving in Brisbane is somewhat less than the Victorian figure.

There are good indications as to what will finally happen in northern Australian waters by looking at which has happened in the relatively short time that large numbers of tropicals have been entering Australia and by referring to the situation in Florida.

Mr. Roley McKay, Ichthyologist of the Brisbane Museum and member of the Aquarium Fish Committee has been looking at the establishment of tropical exotics in Queensland streams. I understand his work is not yet complete but he has told me that perhaps 5 species of tropicals have become established in the Brisbane river system and that other streams far north of Brisbane also have populations of exotic species. Mr. Ian Kirkegaard now living in Adelaide but recently a member of the Fisheries Agency in Darwin (also a member of the present Aquarium Fish Committee) has told me that two species are established in Northern Territory waters.

Before looking at the Florida situation, I would like to stress a significant point about Australia's fishes. We have a depauperate fish fauna. Not only is the number of fishes small in Australian waters compared with others in the world but the fishes we have are with a few exceptions not aggressive free ranging fish eaters. Taking as an example a single point in the Murray-Darling River system, and excluding from our consideration exotic fishes which have become established, it would be unusual to find more than 8 or 10 species of fish present. Of these, perhaps only half would grow to a length of more than a few inches and 3 or 4 species might grow to a greater weight than 3 lb. Although the larger fish may be carnivorous none of them can be considered as efficient fish eaters. The two largest growing species, Murray cod and Golden perch are essentially "bottom grubbers" with a basic diet of yabbies. Both take an occasional goldfish and in recent times it is understood they are feeding well on European carp. In Queensland's north-eastern drainage system, there is a very effective fish predator in some of the northern streams from time to time in the form of the Silver Barramundi and the general position as to numbers of species present that may take fish from time to time is perhaps better than in the Murray-Darling system but here again, there is probably nothing to compare with the trouts and pikes of the northern hemisphere. On the North American continent the situation is quite different. It is not unusual to find 30 or 40 species of fish in the one water. Moreover, 4 or 5 species may be fairly large growing, aggressive and accomplished fish eaters and a sizeable proportion of the other species present may also eat fish from time to time. With this sort of fish population in mind, let us turn to Florida where there are more than 40 varieties and perhaps as many as 25 individual species of tropical aquarium fishes now established. Some 100 million tropical aquarium fishes are sold in Florida each year and more than half of these are grown in the State in fish farms. The establishment of these tropical species in the wild is attributed to escapement from fish farms - not from the release of small numbers which is almost certainly the situation in Australia, but from the accidental release of perhaps thousands. One might also postulate that escapes to the wild from a fish farm may take place over a fairly long period whereas in this country we are probably considering a relatively small number of isolated events.

I am suggesting then that the establishment of an exotic species in Floridan waters is comparatively hard and that the 40-odd varieties have become established only because of fairly substantial releases. In Australia on the other hand, fairly small numbers seem to do the trick very well and I have no doubt that if the number of species and of fish being imported into this country continues without any real restraint, Australia's northern waters will have more than 40 varieties of exotics established in them in the foreseeable future.

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PALAEOLIMNOLOGY FOR PALAEONTOLOGISTS*

By W.D. Williams

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Introduction

When first invited to lecture to a group of palaeontologists, my reply was that I had little to say that I thought would be of interest. On pressure, however, I did have to admit that there is one area of limnology which does overlap with palaeontology *sensu stricto, viz.* Palaeolimnology. From then on, it was no use disclaiming that I was not that sort of limnologist: I was a limnologist: that was enough. There you have the bald explanation of my presence here tonight!

The Rationale of Palaeolimnology

Here are some statements about the nature of palaeolimnology:

Bradley (1963): "A prime objective of palaeolimnology is to illuminate the evolutionary stages through which a lake has passed."

Frey (1964): "Palaeolimnology is concerned with the origin and geomorphic history of lake basins and the response of the lakes in them to climate and to changing inputs of water and of various dissolved and suspended substances."

Wetzel (1975): "Palaeolimnology focuses on the sedimentary changes and diagenetic processes that can alter that record [lake sediments], with the ultimate goal of gaining insight into past conditions, productivity, and changes in regulatory parameters that have caused the lake system to enter a different stage of productivity."

To give a wider perspective to these quotes I should add that palaeolimnology is not just the history of lakes: it is much more than that, for at any given time lakes are sensitive and responsive reflections of climatological, geological, and biological events taking place in their catchment basins, as well as within the lake itself.

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* Based on a talk delivered to an informal group of palaeontologists at Flinders University, 26 April, 1977.

The results are to various degrees preserved in lake sediments. It is the interpretation of these preserved results which allows much to be inferred about the causative events. An important point here is that lakes are not microcosms unto themselves; they are in a sense the integrated product of many phenomena in a much larger system - the total catchment basin and lake. It has been claimed - but it appears we have a long way to go - that eventually palaeolimnologists will be able to provide detailed interpretations of palaeoclimates, watershed conditions, water budgets, nutrient budgets, past productivity and the course of eutrophication. And besides, the remains of organisms preserved in the sediments provide a vast store for biogeographical, evolutionary and modern ecological studies.

After all that, I wonder why I'm not a palaeolimnologist!

Predictably, one can find a suitable and erudite quote from G.E. Hutchinson to provide the last word. I found it in the final paragraph of a short essay he wrote many years ago entitled "The History of a Lake" and first published in the *Yale Scientific Magazine* but reprinted in his book "*The Itinerant Ivory Tower*" (1953).

> "The mechanism of the growth of the totality of living matter in a restricted environment, the dynamic relations of its component parts, and the changes in the efficiency of the utilization of sunlight, the sole source of biological energy, by the organism of an isolated and well-defined area of the earth's surface are very little understood. A complete knowledge of the laws involved in such a phenomenon might be of the greatest practical importance; a rational feeling for the equilibria involved must be inculcated into the minds of future men of affairs if we are ever to achieve that harmonious existence which alone will justify the evolutionary ascendance of our species. We can only hope that the restricted studies here described may do a little to add to the great body of knowledge of this aspect of ecology, which with patience and continual effort will slowly develop to ennoble the life of man."

THE STUDY OF QUATERNARY LAKES

An important point to be made here is that most extant lakes are geologically very young, and thus palaeolimnology for the most part is concerned with a time scale of somewhat less than 25,000 years. Of course, some existing lakes are older, but not many, and, unfortunately, for the older ones, palaeolimnological data are sparse. Lake Baikal is probably of middle or early Tertiary age (Kozhov, 1963). There are a few others, mostly in Africa.

The Sedimentary Record

Sediments accumulating in lake basins have numerous sources, but are greatly influenced by the geomorphological nature of the lake basin and its catchment. The primary material basically results from the local interaction of climate and geology, but is frequently much modified by lake conditions. Thus, wave action and currents may rearrange material into coarser or finer particles within the lake, and resuspension and redeposition of material is an ever-present difficulty for all palaeolimnologists. To this primary sedimented material is added chemical substances, both inorganic and organic, which are a manifestation of *in situ* conditions at the time.

Inorganic evidence. The most simple of chemical determinations, *viz.* the determination of the ratio of inorganic to organic material, is frequently very instructive. Linsley Pond sediments near New Haven, Connecticut, studied by Deevey (1942) will serve to illustrate the point. The pond is some 12,000 years old, and the lower-most layers, i.e. first above the original lake floor, were inorganic and mineralized. Above these (ca. 1 metre from bottom) the sediments rapidly increased in organic matter which stabilized finally at about 60%. These represent material laid down under eutrophic (i.e. anaerobic or not fully aerobic) conditions. It is easy to generalise: Linsley Pond formed when Pleistocene ice retreated from New England, was oligotrophic for a short period, and then became eutrophic. In many examples, there is a relatively large increase in organic material just after formation of the lake. It seems reasonable to attribute this to a period of high productivity immediately following lake formation due to release of easily leached material from the catchment into the lake (and perhaps also to some inundation). Whatever the case, the occurrence of such high organic fractions negates the old theory that all lakes begin as oligotrophic environments, and, by a process of limnological evolution, pass into a eutrophic state. The palaeolimnological evidence is that a lake is as productive at any given time as its catchment determines.

Interpretive use has been made of a large number of specific inorganic substances preserved in sediments. They include Na, K, Ca, Mg, Mn, Fe, P, N, SO_4, Cl, HCO_3, Si, Ti, Al, Ga, Zr, Cu and others. Insufficient time precludes detailed mention of examples, but a few deserve at least brief comment.

High inputs of Si and HCO_3 *vis-à-vis* low inputs of Si and a dominance of Cl into the sediments of some closed lakes of East Africa (Hecky & Kilham 1973) have been correlated with weathering rates and thus climate. Humid conditions produced high [Si] + [HCO_3]; acid conditions low [Si] and high [Cl].

The input of biologically inert elements such as titanium, which is extremely conservative, allows better estimation of erosion rates than does the input of biologically reactive elements.

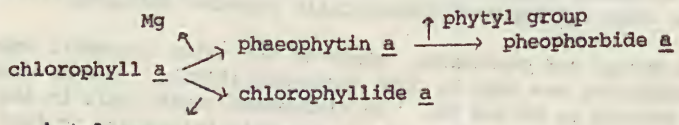
An early, and pioneering, study of the major inorganic ions in lake sediments was made by John Mackereth (1966). Let me discuss only his results on Mn and Fe. In Windermere south basin in the glacial clays, the ratio of Mn : Fe is approximately equal to that

of igneous rocks - indicating a purely erosional transport of both elements. In the organic post-glacial sediments, however, [Mn] increases five-fold, though [Fe] does not markedly increase. This appears due to there having been a preferential erosion of Mn due to the onset of reducing conditions in the developing soils of the catchment basin which were of a strength to produce manganous (soluble) but not ferrous salts. In Windermere, the manganous salts were oxidized to MnO_2, deposited in the sediments, and preserved there since overlying water never became deoxygenated, i.e. reducing. A different story applies to Esthwaite. Again glacial clays have a Mn : Fe ratio similar to igneous rocks, and again, early post-glacial sediments have high [Mn] relative to [Fe]. However, a fall in the [Mn] rapidly follows to a value about half that in the glacial clays. The explanation seems to be that as long ago as 8,000 years B.P. anaerobic conditions developed in Esthwaite in the summer and thus the insoluble and oxidised form of Mn became reduced and soluble. Consequently it was lost to the lake in the lake effluent. The development of anaerobic conditions in Esthwaite undoubtedly resulted from the greater productivity of this lake relative to Windermere.

[P] in sediments is also of much interest because it too can tell much about lake productivity. Moreover, P is relatively immobile. The recent large increases in [P] in the surface sediments of many eutrophied lakes provides the palaeolimnological record of the discovery of detergents! Perhaps the most thorough palaeolimnological documentation for a eutrophied lake is that for Lake Washington, Seattle (Edmondson, e.g. 1969, 1974).

Organic evidence. A variety of organic compounds have been isolated from lake sediments: amino acids, carbohydrates, chlorophyllous, flavinoid and carotenoid pigments, and alkanes (saturated hydrocarbons) are some of the more important (Vallentyne, 1969). There are many more, e.g. phycobilins and porphyrins. However, a number of difficulties are involved in their use as palaeolimnological indices. It is, for example, difficult to know sometimes whether the organic compound was produced *in situ* or in the catchment basin. Differential rates of degradation is another difficulty; degradation is not always a uniform process. That degradation in fact occurs is, of course, another. And it is not easy to distinguish time, origin, and synthetic mechanisms for many organic molecules. For these and other reasons, it appears that although a good deal of information is available on organic compounds in lake sediments, it is of limited palaeolimnological use at present. Nevertheless the field is said to promise much for the future.

The one exception to the equivocatory value of organic evidence is provided by preserved plant pigments: so-called fossil pigments. Brown (1969) has given a recent review that I read in connection with this talk. Upon the death of the plant, the pigments are degraded by loss of side groups and ions (e.g. Mg) and the products tend to decrease in solubility and therefore increase in stability. Thus:-



Chlorophyll a itself is rare, but the other degradation products are common, together with bacteriochlorophyll degradation products, and several carotenoids (some specific for certain groups, e.g. myxoxanthin, myxoxanthophyll and oscilloxanthin (Oscillatoriaceae only) for blue-green algae). Large pigment concentrations in recent sediments can be clearly correlated with rapid eutrophication of many lakes in recent decades, and related man-made phanomenon, e.g. deforestation. Sometimes, however, decrease in pigments may signify a man-made productivity decrease. Wetzel (1970) gave an example: deforestation of certain lake catchment basins caused massive input of $CaCO_3$ which suppressed productivity as indicated by decreased fossil pigment concentrations.

Though less useful than pigments, alkanes* provide some clues to past history. The higher alkanes from C_{15} onwards are colourless solids and occur in plants. Higher plant residues yield mostly C_{27}, C_{29}, C_{31}, and C_{33} alkanes and small amounts only of C_{26} .... C_{34} alkanes. In algae and other lower plants, residues are C_{25} - C_{34} with C_{17} the main alkane component. Thus, the relative contributions of higher plants and algae to lake sediments can be estimated. Estimates have even been made on sediments of Eocene age (in this case, the alkanes were clearly from algae, proving that the sediments were laid down in lake conditions).

Other Evidence. Though considerable care is needed in interpretation, much can be learnt of past conditions merely from examining the gross physical structure of lake sediments. Thus in some lakes varves are laid down - varves being sedimentary layers laid down at regular intervals, usually two per year. From these it is possible to make direct estimates of age and sedimentation rates. The latter reflect in very close fashion erosion rates on the catchment, a phenomenon which itself may be subject to further explanation. Unfortunately relatively few lakes show clearly varved sediments, but even so gross sediment composition provides useful information. Thus in the lakes of the English Lake District - which have been examined rather well - the "bottom" end of the sediment in lakes comprises stony clays: these were clearly deposited during the Ice Age. Silty detritus mud follows and represents an amelioration of glacial conditions. A further band of stony clay implies the recurrence of glaciated conditions. The overlying topmost layers of brown mud represent the accumulated sediments of the post-glacial. Nearer home, the presence of volcanic ash in the deepest layers of certain lake cores from the Western District of Victoria tells its own story.

A celebrated example of the relationship between rate of sedimentation and events in the catchment basin is provided by the Lago di Monterosi (Ianula) (Hutchinson *et al.*, 1970). The lake is

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*Saturated aliphatic hydrocarbons of formula C_nH_{2n+2}

near Rome and was formed some 25,000 years B.P. It was quite productive in its early years because of inputs of easily leached material from the catchment. Then it became rather unproductive as evidenced by low rates of inorganic deposition (and organic accumulation). This phase continued until a very large increase in sedimentation occurred about 2,000 years B.P. This can be correlated pretty precisely with a major disturbance in its catchment basin, namely the construction of the Via Cassia by the Romans. Since that time sedimentation has declined but never to its former, pre-Roman, levels.

Another, and more local, example of how much a study of the gross physical nature of lake sediments can contribute is provided by Bowler and Hamada's (1971) study of sediments from Lake Keilambete, Victoria. Other evidence was considered, but largely on the basis of the 'geological' nature of the sediments correlated with C_{14} dates, they were able to provide a pretty precise chronology for the lake from the time of its origin (~30,000 B.P.) and for the associated palaeoclimatic fluctuations.

Much of interest can also be gained from a study of former lake levels - not only for palaeolimnologists but for climatologists, geologists and archaeologists (Richardson, 1969). Indications of former low levels include deposition of coarse sediments offshore, missing pollen zones, evaporite deposition, and changing patterns of littoral aquatic plants. High levels are indicated especially by abandoned beach terraces. Currey's (1964) study of the former extent of Lake Corangamite, Victoria, is a particularly interesting local example of such a study. The study of dry lake beds and of lunettes (crescentic dunes associated with present-day lakes or with former lakes) can also contribute much of palaeolimnological interest: indeed, Bowler (1971) puts the case most emphatically for Australian studies: "Some of the best evidence of past hydrologic and geochemical environments is provided by the transverse crescentic dunes or lunettes which occur on the eastern shores of most lake basins in the semi-arid zone of both southeastern and southwestern Australia."

The Biological Record

A large number of plant and animal groups leave remains which become preserved in lake sediments. Usually fractional, they nevertheless frequently can be matched to species. When only parts of a life-cycle are preserved, then identification is usually to higher taxonomic status (genus or family only).

Evidence from plant remains. Plant remains comprise pollen, diatoms, some green algae, Chrysophyceae, dinoflagellates, parts of blue-green algae, and various fractions of other plant tissues. Of these, pollen is undoubtedly the most important, and all comprehensive palaeolimnological studies involve an analysis of pollen stratigraphy. Tutin (1969) puts it succinctly: "The most informative single clue to the history of the environment in the drainage basin, as yet discovered, is analysis of the pollen spectrum of the lake sediments." Note: it is the vegetation of the drainage basin which is involved, not that of the lake.

Little need be said on the subject of pollen stratigraphy since presumably most of the audience will be more familiar with the subject than am I. However, in case not, a few brief notes are in order. Pollen stratigraphy is the record of the chronological and geographical distribution of fossil pollen and spores preserved in sediments (not necessarily those of lakes only). As such, pollen stratigraphy is a branch of palynology, the study of all aspects of pollen and spores. Pollen comprises microscopic (5 - 200 µm) reproductive structures produced by the male reproductive apparatus of the higher plants (angiosperms and gymnosperms). Morphologically complex, they have one to many apertures that are round to ellipsoidal (usually), or elongate, and have complex surface patterns. Spores (5 - 200 µm) are reproductive bodies produced by the lower vascular and by non-vascular plants. Typically they are kidney-bean shaped or triangular and have smooth or ornamented surfaces. Both pollen and spores have outer walls (the exine) which is highly resistant to decay; the compound involved has been termed sporopollenin (little apparently is known of its chemical construction). The important point in relation to pollen stratigraphy is that although little is indicated of lake *in situ* conditions, and although it is difficult to construct past vegetation in the catchment basin at any one time, changes in pollen spectra from one level to the next can be related to environmental changes in the drainage basin over periods of time. It is the dynamic aspect that gives pollen stratigraphy its importance.

A number of pollen stratigraphies from lake sediments have been constructed in Australia. A comprehensive but obscure one - and I mention it because of those reasons - is that by Yezdani (1970). He studied in a most thorough fashion a small number of volcanic lakes in the Western District of Victoria. A few others: south-eastern South Australia (Dodson and Wilson, 1975); Kangaroo Island (Clark, 1976); Victoria (Hope, 1974); Queensland (Kershaw, 1970, 1974, 1975).

The most important autochthonous plant remains preserved in lake sediments are those from diatoms. There are various interpretive problems, but diatom stratigraphy has much value since extrapolations backwards can be made from the known ecological requirements of present-day diatoms. Thus, as a very general rule, centric diatoms are associated with oligotrophic environments of low productivity, and pennate ones with eutrophic, productive conditions.

Evidence from animal remains. It is claimed that almost all groups of animals leave at least some fragments of their anatomy for subsequent preservation; however, the number and sorts of animal fragments usually preserved are relatively limited in scope. They comprise certain parts of Cladocera and midges (Chironomidae, Ceratopogonidae, and Chaoboridae); ostracod valves and rhizopod tests are also preserved in special circumstances, as also are sponge, rotifer, turbellarian and bryozoan fragments. Larger preserved animal remains are mostly mollusc shells, beetle fragments and fish scales and vertebrae. Quite why there is such differential preservation is not always clear.

Exoskeletal cladoceran remains include the carapace, ephippial shell, head shield, postabdomen, mandible and a few other minor fragments (Goulden, 1969). These usually enable identification to be taken to species level. For some reason chydorid Cladocera, relative to other cladoceran families, are especially likely to be preserved; indeed, chydorid remains are frequently the most abundant animal remains in sediments. However, I know of no Australian study of cladoceran remains (which is, no doubt, a part reflection of the difficulties of cladoceran taxonomy in Australia). Perhaps it should be noted therefore that these difficulties are likely to be somewhat less in the near future, for a small number of workers have recently taken interest in the group - most notably Professor N.N. Smirnov, Moscow, who was in Adelaide recently in connection with an ongoing taxonomic revision of Australian Cladocera.

The commonest insect remains are the head capsules of midge larvae, particularly those of the family Chironomidae. In a sense this is particularly fortunate for a great deal of work has been directed towards relating living chironomid species with lake types (beginning with Thienemann, 1920). Thus, as a general rule in the northern hemisphere, stratified lakes that are oligotrophic are characterized by *Tanytarsus*, mesotrophic lakes by *Stictochironomus* and *Sergentia*, and eutrophic lakes by *Chironomus*. This scheme was once thought to apply also in the southern hemisphere (Brundin, 1958), but that seems not to be the case in Australia (see discussion by Bayly and Williams, 1973). At least in the northern hemisphere, it would then seem simple to relate chironomid remains with lake type at the time of deposition. In practice, it is not so simple, and there are many interpretive difficulties (Stahl, 1969). One Australian example may be mentioned at this point. Paterson and Walker (1974) studied a core of sediment from Lake Werowrap in the Western District of Victoria. At various levels they found head capsules of *Tanytarsus barbitarsus*, a halobiont, *Chironomus duplex*, a freshwater species, and *Procladius paludicola*. They related these records to changes in the salinity of the lake; when salinity was high *T. barbitarsus* occurred, sometimes with *P. paludicola*, a facultative predator; when salinity was low, only *C. duplex* occurred. Data upon salinity tolerance of living specimens provided experimental back-up to their suggestions.

Ceratopogonid remains are rarer: all are of larvae, and again it is the head capsule that is preserved. Ceratopogonid larval taxonomy is scarcely healthy in Australia at present; it seem unlikely therefore that any stunning example of ceratopogonid stratigraphy will eventuate from any study of Australian lake sediments within the near future. None exists at present! At the same time it may be remarked that ceratopogonid larvae are a peculiarly abundant faunal element in many Australian salt lakes *vis-à-vis* salt lakes elsewhere.

Chaoborid remains mainly take the form of larval mandibles, though other fragments may be preserved (respiratory horns of pupae). As chaoborid larvae are said to characterize highly eutrophic lakes, the occurrence of their remains implies the occurrence of high rates of organic deposition and productivity, and low $[O_2]$ at the time of preservation. Chaoborid larvae, however, have been found in quite

nutrient-poor impoundments in Australia, so it is clear that all is not as simple as might be implied.

Much less need be said about other animal remains. Ostracod valves have been less studied than cladoceran or midge remains but are by no means uncommon. They were, for example, recorded in large numbers by Yezdani (1970). The same comments apply equally well to mollusc remains. These, too, were recorded by Yezdani for he noted the occurrence in various sediment strata of *Coxiella* shells (gastropod shells). Since there is but a single species of *Coxiella* in southeastern Australia, and this is restricted to mildly saline lakes (2.4 - 29.4°/oo salinity), an obvious correlation can be drawn between its occurrence and corresponding lake salinity. Turbellarian remains comprise egg cocoons, bryozoan remains are statoblasts, poriferans are represented by their characteristic spicules, and rotifers by resting eggs.

Dating methods. The C_{14} dating technique is by far the most important dating device there is in palaeolimnological studies; its time scale, 500 - 50,000 years B.P. overlaps almost completely with the age of most lakes, <100 - 25,000 years B.P. It is, however, not useful when sediments are contaminated with allochthonous carbon as in the English Lake District where the presence of charcoal from human induced sources leads to unacceptable C_{14} figures. Other isotope dating techniques apply to a much longer time scale. Two other dating techniques are useful in palaeolimnology, particularly so far as recent sediments are concerned. One involves the determination of the compass direction of Fe particles in sediments; (remanent magnetism); the palaeomagnetic direction reflects the polarity of the particles when deposited, and this can be equated fairly precisely with former magnetic deflections (e.g. Mackereth, 1971). The other involves another form of radiometric dating: this time the isotope concerned is Cs_{137}. This isotope has been present in the atmosphere since 1954, but not previously. It is relatively immobile in sediments and hence provides a unique datum in recent sediments.

THE STUDY OF PRE-QUATERNARY LAKES

Whilst it is true that most palaeolimnological endeavours have been concerned with lakes of fairly recent origin, lest it be thought that all endeavours have been so I propose to conclude by referring briefly to various studies of palaeolimnological interest on lake sediments very much older. Before doing so, however, I should note that several animal groups - so far as known - are and always have been restricted to inland water bodies: most aquatic insect larvae, and branchiopods provide examples.

One of the 'oldest' palaeolimnological studies is that of Tasch and Zimmerman (1961). They studied some Permian sediments in Kansas and Oklahoma and concluded, largely on the basis of conchostracan fossils and a comparative study of sediments, that they were dealing with a Permian pond that had probably been very shallow, temporary, turbid and free of currents. Other pre-Quaternary palaeolimnological studies include those of Anderson and

Kirkland (1960) on a lake of Jurassic age in central-southern United States, of La Rocque (1960) on a large lake of Palaeocene/Eocene age in Utah, and of Bradley (1963) *et al.* on lakes of Eocene age in the Green River Formation of Wyoming, Colorado and Utah. Both plant and animal fossils have been utilized in these studies. The most important animal fossils have been of fish, conchostracans, ostracods, bivalved and gastropod molluscs, tortoises and crocodiles. However, a much wider variety of aquatic arthropods has been recorded in other palaeolimnological studies of pre-Quaternary lake sediments - including fossils of some groups which are rarely if ever found as subfossils (e.g. cyclopoid and harpacticoid copepods). In fact, Mr. Russell Shiel, a Ph.D. student of mine, presently holds for description a fossil calanoid copepod of putative Eocene age. It was found near Anglesea, Victoria.

The great age of pre-Quaternary sediments means of course that C_{14} dating is quite inapplicable. Other radiometric dating techniques, however, are available, namely $Uranium_{238}/lead_{206}$, $Uranium_{235}/lead_{207}$, $rubidium_{87}/strontium_{87}$, and $potassium_{40}/argon_{40}$. The potassium/argon method is particularly useful. Isotopic geochemistry also has a role to play in palaeolimnology other than as a dating tool. Thus isotopic fractionation processes may be informative for palaeoenvironments. The proportions of O_{16} and O_{18} in calcareous fossils provides a means of estimating temperature at the time the animal lived. The proportions of C_{13} to C_{12}, and of S_{34} to S_{32} may give clues on lake metabolism and microbial activity (Deevey *et al.*, 1964).

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PROBLEMS ENCOUNTERED IN THE MEASUREMENT OF THE HIGH TURBIDITY OF SOUTH-WESTERN AUSTRALIAN FARM DAMS

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Introduction

Production of marron (*Cherax tenuimanus*) has been studied recently (1974-76) in fifteen farm dams located in the Great Southern wheatbelt area of W.A. (finance - Australian Fisheries Industry Research Trust Account).

Measurement of the usually high clay turbidity of these dam waters was relevant to the following aspects of crayfish ecology. Measured as a concentration of suspended particulate matter, the clay is a primary constituent of these dam waters sometimes exceeding salinity; concentrations of clay-silt ranged up to 2,600 mg/l (a montmorillinite clay dam) or 1,280 mg/l (the majority, kaolin clay dams) while salinity was in the range 178 - 1,126 mg/l. Together with, mainly, allochthonous organic matter, flocculated clay formed the primary component (about 90%) of the dam sediments upon which the crayfish fed selectively. Alternatively turbidity could be measured as the degree of light penetration by various types of instrumentation. The greatly reduced light intensity experienced by bottom-living marron in turbid farm dams (Secchi depth ranged from 2.5 cm (montmorillinite) or 4.0 cm (kaolin)) resulted in the feeding rate, as measured by the catch rate in baited drop nets, being high during daytime instead of being restricted to the early night time as in clear water (Morrissy, 1974a). This factor also prevented bird predation, a major cause of mortality in clear water dams or commercial marron farming ponds if there is little or no refuge shelter (Morrissy, 1974a, 1976a). Because of high turbidity, daytime heating of farm dams during summer was restricted to the immediate surface layers, resulting in extreme but ephemeral daytime temperature stratification, which promoted rapid air cooling overnight and (near) equilibration of the water mass by early morning allowing reoxygenation of bottom water via wind induced circulation (Morrissy, 1974a). Back scattering of solar radiation by suspended white clay particles enhances the albedo or reflection of radiation from the water surface resulting in lower surface temperatures and general heating of a water mass (Schiebe *et al.*, 1975).

Concentration of Suspended Clay

Subtraction Method. Total solids were measured by evaporation of a 300 ml sample to dryness at 105°C (2 days). Total dissolved salts were calculated from conductivity. Total suspended matter (plus dissolved organic matter) was calculated by subtraction using the above values. Total suspended clay was calculated by further subtraction of total organic matter (particulate and dissolved), measured by ignition of the dried total solids at 550°C for three hours in a muffle furnace.

Filtration Method. Estimation of the size distribution of suspended clay-silt particles *in aquo* by the simple technique of filtering known volumes of subsamples, from the well-shaken sample of dam water, through a range of filter sizes gave satisfactory results. The cumulative size frequencies distributions obtained also gave estimates of total clay concentration (Fig. 1). Filter sizes (47 mm dia.) were 12 µm (Sartorius), 8, 3, 1.2, 0.45, 0.1 and 0.025 µm (MF-Millipore) (fine clay <0.2 µm, clays in general <2 µm, "silt" 2-20 µm). Weight of filtrate, and hence concentration in the original sample, was determined after ignition of the filter paper at 550°C, and redrying at 110°C, following cooling in the muffle furnace, using small crucibles (Halden-Wanger, Berlin, type 9MF). Filtration was performed at a negative pressure of 250 mm Kg. Great care was taken to prevent filter clogging which yielded overestimates due to retention of finer particles; volumes filtered were adjusted proportionally to filter size by watching the rate of flow of the filtrant and, if necessary, replication was carried out after graphical examination of the first series of data for a sample. Residual filter ash (of non-grid paper) was negligible (12 µm - 0.025 mg, 0.025 µm - 0.056 mg) in relation to the smallest volumes filtered (5 ml) and sub-sample weights (4 mg), i.e. about a maximum of 1.4% by weight of the estimate.

Bias in the Subtraction Method

Comparison of estimates of clay concentration (mg/l) by the subtraction (x) and by the filtration methods (y) gave a significant regression relationship ($P < 0.001$), $y = 133 + 1.2x$, $n = 27$ and correlation coefficient (r) = 0.8746, indicating an average underestimation of 133 mg/l by the subtraction method.

The effect on electrical conductivity (K_{20}) of adding white kaolin clay, obtained from the Kohonup area, to Perth tap water ($K_{20} \approx 500\ \mu Scm^{-1}$) was to progressively reduce the K_{20} value over a period of several months. A maximum reduction of 3.2% occurred at 1,500 mg/l by three months (range tested 500 - 5,000 mg/l of clay added). These tests suggested that the addition of negatively charged clay particles reduced K_{20} by neutralizing cations but that the charged clay particles also contribute to conductivity. The latter was shown by the effect on K_{20} of removing suspended clay from a turbid water sample, $K_{20} = 625$; using a 12 µm filter K_{20} was reduced to 620 and with a 1.2 µm filter to 610 (2.4%).

The estimation of clay particle size distribution by the filtration method showed that the dam waters often contained significant concentrations of suspended clay smaller than 0.45 µm. The latter is the conventional filter size used to remove suspended matter before analysis for total dissolved solids (T.D.S.) by evaporation and for salinity by summation of estimates of individual ions. Previously values of 0.65 for the ratio T.D.S./K_{20} for farm dams (Morrissy 1974a) and of 0.64 for both the ratios of T.D.S./K_{20} and salinity (mg/l)K_{20} were found for nonturbid river water in the farm dam region (Morrissy, 1974b). For the present series of farm dams, examination of the data from bi-annual analyses using prior 0.45 µm filtration showed that overestimations of both T.D.S. and salinity often occurred due to the presence of residual clay.

The values of the above ratios were often much higher than the previous values of 0.64 - 0.65 and the value for T.D.S. was often exceeded by the value for salinity, a component of T.D.S. (Fig. 2). The most obvious bias occurred in values for a highly turbid dam, D6, where particle size analysis for a water sample taken in May 1975 showed that 32.5% of the 1680 mg/l of clay was less than 0.45 µm in size (Fig. 1.).

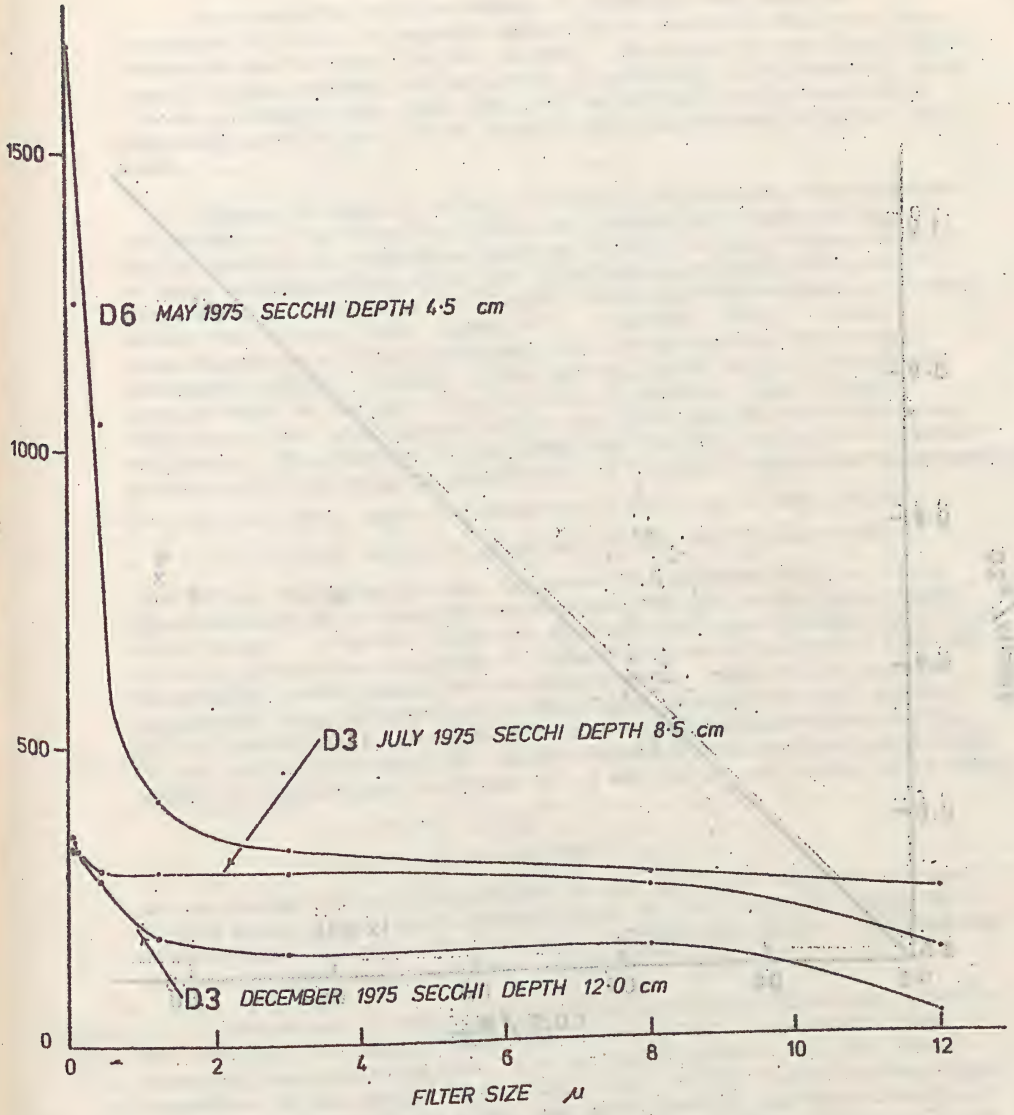

Figure 1. Estimation of suspended clay-silt by the filtration method for two farm dams; D6 - mainly montmorillinite clay, D3 - kaolin clay.

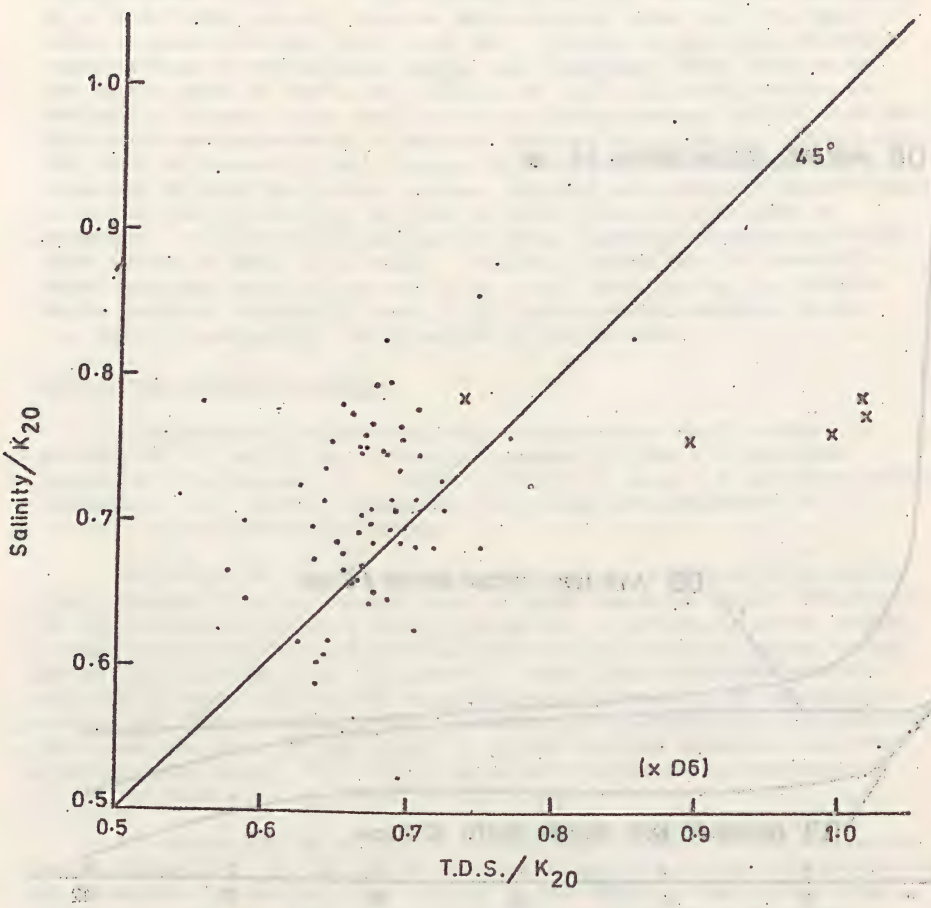

Figure 2. Comparison of salinity/conductivity and total dissolved solids/conductivity ratios for farm dam waters with 0.45 um filtration prior to analysis.

No acceptable routine method of obtaining very accurate estimates of T.D.S. or salinity appear to be available when very high concentrations of fine clay are present; obtaining the volume of clay-free filtrate necessary for analysis, is extremely time-consuming using filters of smaller pore size than 0.45 µm and may be only marginally successful particularly in the case of red clay (montmorillinite - D6) dams).

Losses of volatile salts, principally bicarbonate (no carbonate was present in the farm dam waters) and mechanically occluded water during ignition of evaporated residues could have given overestimation of total organic matter while loss of bicarbonate during the prior evaporation to dryness at 105°C could result in underestimation of total solids (Hutchinson, 1957; APHA, 1971; Paterson, 1973). Hence underestimation of total suspended clay, by subtraction from total (suspended) solids of total organic matter, could result. Since the average value of the most volatile ion, bicarbonate, was 112 mg/l, this factor was investigated further for these samples where the error was known. Bicarbonate (y) was predicted from K_{20} (x) by one or other of two, quite distinctive, significant ($p < 0.001$), regression relationships,

$y = -45.6 + 0.373x$ with $n = 42$ and $r = 0.8776$ for 10 dams and by

$y = -74.7 + 0.251x$ with $n = 26$ and $r = 0.8267$ for 6 other dams.

(The actual relationships are, of course, curvilinear but the linear equations provide an adequate description over the conductivity range encountered.) However, there was no significant relationship ($P = 0.45$) directly between the magnitude of underestimation of suspended clay and bicarbonate concentration for individual dams. Most of the loss of bicarbonate could be expected to occur upon ignition of total solids, giving overestimation of organic content. Percentage organic matter (y) was not significantly ($P > 0.05$) related to the ratio salinity/total solids but significantly related ($P > 0.01$) to the ratio HCO_3/total solids (x),

$$y = 9.142 + 38.3x$$

$$n = 30 \text{ and } r = 0.4580$$

For an average value of bicarbonate of 112 mg/l, the slope coefficient of this equation indicated overestimation of total organic matter by 43 mg/l, due to bicarbonate loss upon ignition, and partly accounted for the underestimation of suspended clay by 133 mg/l.

The amount of water retained when solids were dried out at 105°C but lost upon ignition at 550°C was investigated. For kaolin clay, obtained from a farm dam bank, loss on ignition was 0.46%, and after suspension of the sample in distilled water, 0.59%, following oven drying at 105°C. Alternatively water loss upon ignition averaged 1.05% for seven sediment samples containing organic matter (range 12.7 - 18.1%, as measured by loss on ignition). The loss was calculated from the difference in sample weights before and after rehydration of the ignited sample with distilled water. These estimates of loss of water on ignition were insufficient to account for more than a very small part of the underestimation of total suspended clay by the subtraction method in farm dam waters.

No satisfactory method was achieved for full correction of the underestimation in estimates of total suspended clay concentrations by the subtraction method in the fifteen, or so, farm dams studied.

Nephelometry

Measurement of the turbidity of farm dam waters as the degree of light penetration also presented a number of problems due to bias. The usual range of turbidity as measured by the Secchi depth in the field was 4.5 cm to about 20 cm. More precise field measurement using a transmission (α) meter was not adopted because of the very high price of these meters, the long (1m) light path suited for clear water, and the cumbersome nature of the apparatus. Instead a much less expensive laboratory nephelometer (Hach model 2100A), employing the side-scattering rather than transmission principle and formazin standards, was adopted as recommended by APHA (1971).

Undiluted water samples were analysed after standing for two days on the laboratory bench and then reanalysed following thorough mixing.

Dilution was recommended by Hach to bring a highly turbid sample within range of the meter, which has a maximum value of 1,000 formazin turbidity units (FTU). All the undiluted water samples gave readings within the range of the meter and preliminary correlations with the Secchi depth and the estimated concentration of suspended clay appeared to be realistic except in the case of the most turbid dam, D6, where the reading was much too low (300-400 FTU). Moreover, when the turbidity of D6 increased the FTU value decreased and values of settled samples were higher than those after mixing.

APHA (1971) recommended dilution of all turbid water samples, to a low range of less than 40 FTU, with distilled water to prevent this blacking-out effect. However, since clay turbidity is highly dependent upon salinity and the ratio of monovalent to divalent cations (unpublished data), distilled water cannot be used for dilution (see below) and the sample water, free of any suspended matter, may be used (nephelometry is independent of dissolved matter, i.e. colour, due to organic matter). Analysis of these highly turbid samples for particle size distribution by the filtration method, developed late in the programme, showed that the conventional filter size of 0.45 µm would not remove all the suspended clay (APHA (1971) recommended that turbidity-free distilled water be obtained by use of filter sizes no greater than 0.1 µm). The small volume (2.5 ml) of filtrate obtained through filters of these smaller pore sizes before clogging halts filtration, makes the task of obtaining to 20 or so mls of filtrate necessary for dilution of each turbid farm dam water sample extremely tedious. Progressive dilution of highly turbid water samples with distilled water (APHA 1971) gave increasing values of estimated turbidity probably due to dissociation of clumped clay particles with decrease in salinity. This effect was particularly marked for the dam D6 where fine montmorillinite clay was present, in contrast to kaolin in the other dams (Fig. 3).

Although nephelometry was recommended by APHA (1971), and the units of the formazin standards are comparable to the long-used Jackson Candle units, a recent overview (NOIC 1974; Pickering, 1976) emphasised the difficulties of interpretation encountered in the W.A. farm dam study. Values obtained by both nephelometric and transmission methods are influenced by variation in particle size occurring seasonally or between different waters, as well as by total concentration of suspended matter. Although nephelometric values are independent of dissolved matter (colour), the more expensive but standardised transmission methods, using an α-meter or submarine irradiance meter (Kirk, 1977), have the advantage of yielding absolute values and appear to be preferable to the rather primitive methods in current use in Australia (Lyons and Parker, 1973).

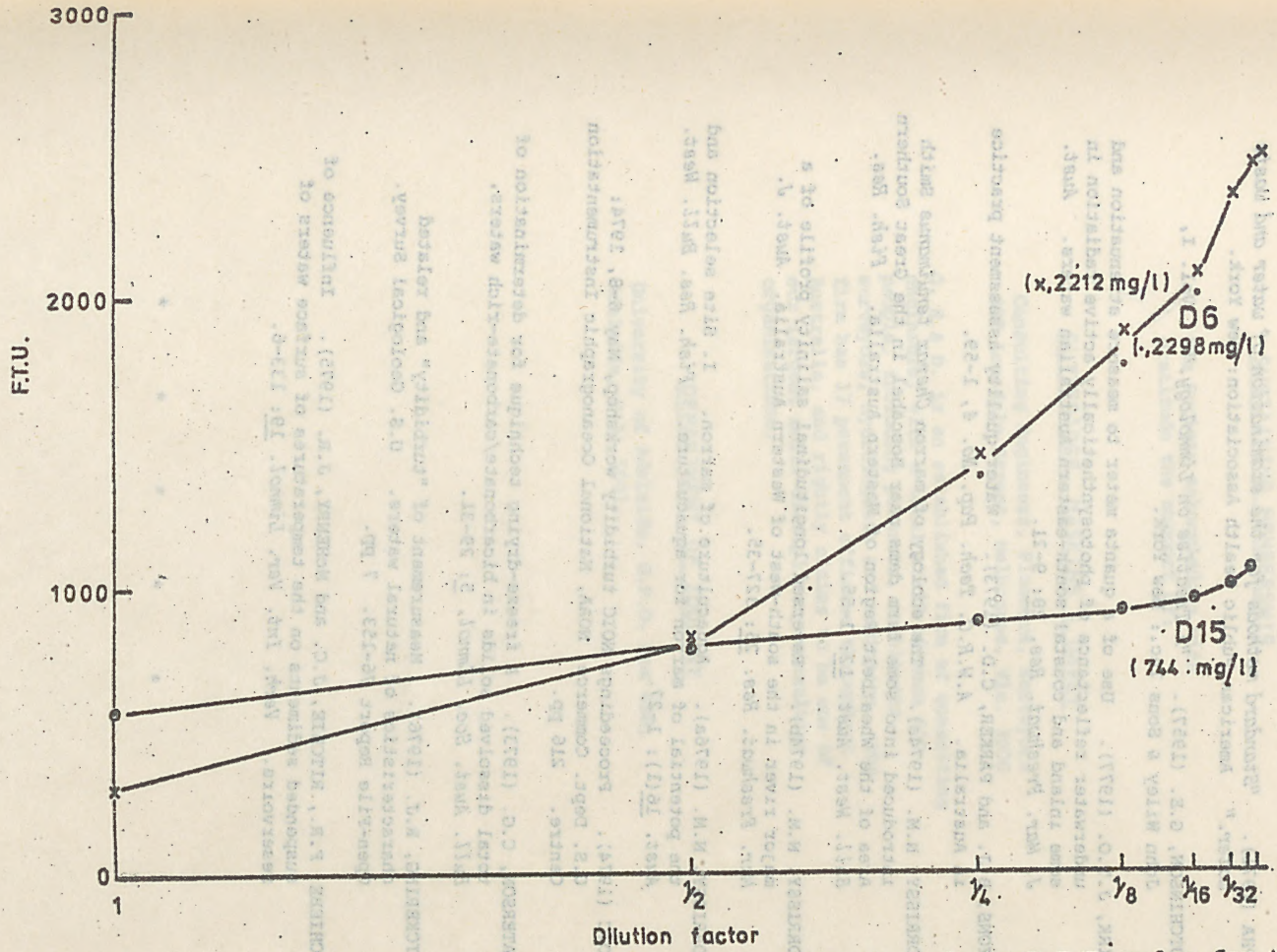

Figure 3.

Effect of progressive dilution with distilled water on the estimation of the F.T.U. value for two farm dam waters; D6 – total solids 2919 mg/l upper values and 2908 mg/l lower values), D15 – total solids 1051 mg/l; values in parentheses are the total suspended clay-silt concentrations estimated by the subtraction method.

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